Usefulness of synthetic aperture magnetometry for presurgical evaluation in the epilepsy surgery

A. Kato[1], H. Ninomiya[1], M. Hirata[1], Y. Nii[1], M. Taniguchi[1], S. Hirano[1], T. Mano[2], K. Imai[2], E. Kumura[1], H. Nakamura[3], SE. Robinson[4] and T. Yoshimine[1]

Departments of [1]Neurosurgery, [2]Pediatrics and [3]Radiology, Osaka University Graduate School of Medicine, E-6, 2-2 Yamadaoka, Suita, Osaka 565-0871 Japan; [4]CTF Systems Inc. 15 - 1750 McLean Ave.Port Coquitlam, B.C. V3C 1M9 Canada

1   Introduction

Selecting the surgical candidate for medically intractable epilepsy, detection and localization of seizure focus and cerebral functions are essential for diagnosis, for localization of surgical treatment and for prevention of surgical complications. Due to the limitations of noninvasive evaluations, invasive examinations, such as chronic ECoG grid recording, cortical stimulation mapping or amytal test , are often necessary. However, they have disadvantages of invasiveness and sampling error.

Recently developed synthetic aperture magnetometry (SAM) is a novel spatial filtering technique based on the nonlinear constrained minimum-variance beamformer [1][2]. This technique overcomes the nonuniqueness of generalized inverse solutions, such as the minimum norm, and thereby permits ambiguous three-dimensional source mapping. In the present study we have applied two techniques derived from SAM: SAM virtual sensor (VS) method, which enables to measure currento-densitogram of the small portion of the brain with an enhanced sensitivity   as if intracranial electrodes were inserted [3] to estimate the epileptogenic area, and SAM statistical method which detects activated cerebral area during task performance [4].

2   Methods

2.1   Simultaneous recording of EEG and MEG

Nine patients with refractory epilepsy, 5 being temporal and 4 extratemporal, were examined (Table 1). A helmet -shaped 64-channel SQUID system (Model 100, CTF Systems) was used for MEG data acquisition. EEG signals based on international 10-20 electrode configuration were processed on the MEG system to compare both signals on the same time axis. Signals of both interictal spikes and subclinical electrical seizures were collected. A total of 40 raw data sets, each of them comprising of 10 seconds recording, were culled from 2 hours recording so as to include the epileptic activities on EEG.

2.2   MEG dipole analysis

A single equivalent current dipole (ECD) modeling was used to estimate the source of interictal epileptic spike on MEG. ECDs were plotted on MR images scanned with the same fiducial markers that were coordinated with the marker points during MEG recording.

2.3   SAM-VS

SAM virtual sensors were set in lattice of 1.0 to 1.5 cm width (8 patients) in and around the cerebral tissue where abnormal activity was detected by EEG or MEG. The signal from each virtual sensor was inspected every millisecond to determine the origin of epileptic discharge and its sequence of spread. The origin of epileptic discharge was classified according to the anatomical aspects and compared with the results of other preoperative examinations including MRI, MRS, PET, SPECT and MEG-ECD, as well as the final diagnosis determined with chronic subdural grid study, intraoperative ECoG, histopathology and surgical outcome.

2.4   Reading task

A hundred words each consisting of 3-hiragana-character were picked up from a Japanese textbook for elementary school children. Care has been paid to the level of words not being too easy or too difficult. Each word was displayed on the 14 inch TFT monitor in 96 point black Gothic character on the white background. After displaying the background for 3 seconds each word was displayed on trigger for 3 seconds. Patients were instructed to read the word without phonation only one time immediately after each word was displayed. Each trial is repeated 100 times. The raw data were collected at a sampling rate of 625 Hz and filtered with a 200 Hz on-line low pass filter for 2500 msec before and after the trigger (Fig.1). Then it was filtered into frequency

Table 1: The results of preoperative examinations with reference to the final diagnosis

Case No.	Age/Sex	Final diagnosis	EEG	MRI/MRS	PET/SPECT	MEG-ECD	SAM-VS	Outcome (Engel's classification)
1	39/F	rt TLE+ OLE	agree	obscure	agree	agree	agree	III *
2	24/F	rt TLE	agree	HS	agree	agree	agree	I
3	19/M	lt TLE	agree	HS	agree	agree	agree	I
4	11/F	lt TLE	agree	obscure	agree	agree	agree	II
5	23/F	lt TLE	agree	HS	agree	agree	agree	I
6	4/F	lt FLE	agree	GG	agree	agree	agree	I
7	6/M	rt FLE	equivocal	obscure	obscure	fail	agree	II
8	7/F	rt OLE	agree	obscure	agree	fail	agree	I
9	29/M	rt FLE	equivocal	contusion	obscure	fail	agree	II

TLE; temporal lobe epilepsy, FLE; frontal lobe epilepsy, OLE; occipital lobe epilepsy
HS; hippocampal sclerosis, GG; ganglioglioma, rt; right, lt; left
* Surgery was performed only for the OLE due to AVM, the patient is under follow up.

bands and analyzed by SAM statistical method comparing control and active states with different time windows within 0 to 2500 msec. The dominant hemisphere was determined when the event related synchronization or desynchronization of high gamma band appeared in the temporoparietal region and frontal operculum. The result was compared with amytal test.
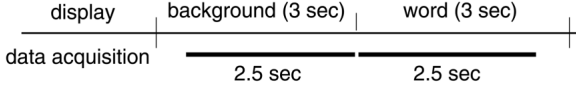

Figure 1: *MEG data acquisition protocol for reading task.*

3 Results

Suspected epileptogenic areas demonstrated with SAM virtual sensor agreed reasonably well with other noninvasive studies including MRI, MRS, PET, SPECT and MEG-ECD in 6 of the 8 patients (Cases No.1-6 and 8). For the temporal lobe epilepsy (Cases No.1-5), good agreement was attained on the diagnosis and epileptogenic zone. For the extratemporal epilepsy, the examination sometimes failed to give concordant results. While the estimates by SAM-VS study always consistent with the final diagnosis.

3.1 Comparison with EEG and SAM-VS currentodensitogram

Case No.9 was a patient with a 20 years history of posttraumatic intractable epilepsy. MRI revealed large cerebral defect in the right frontal lobe. Most of EEG study including video EEG, however, appeared to indicate bifrontal origin. Thus, SAM-VSs were set to cover bilateral frontal lobe (Fig.2a)

In the illustrative case, SAM-VS currentodensitogram clearly disclosed a large spike in the right frontal basal area (channel V09), while EEG demonstrated bilateral positive spikes, with which no localization could be determined as shown on the topography (Fig. 2c). By the careful inspection, electrically still state could be identified on channels V09 and V20 prior to the spikes. Among 40 epileptic events, only a few discharges originated from the left hemisphere. This observation was confirmed with intraoperative grid study.

3.2 SAM statistical method for localization of language -related cortex

The isofield maps have demonstrated field reversals in the occipital area at around 100 msec, in the posterior temporal area at around 230 msec and left frontal area at around 350 msec. Of the five frequency bands, the focal ERD manifested rather consistently in the gamma band. The SAM statistical image demonstrated ERD in the occipital cortex in 6 patients, in Wernicke's area in 3 patients, in the angular cortex in 2 patients, in the supramarginal cortex in 2 patients and close to Broca's area in 5 patients. The ERDs in the cerebellum, left temporal base and right hemisphere especially in the temporoparietal cortex were observed occasionally.
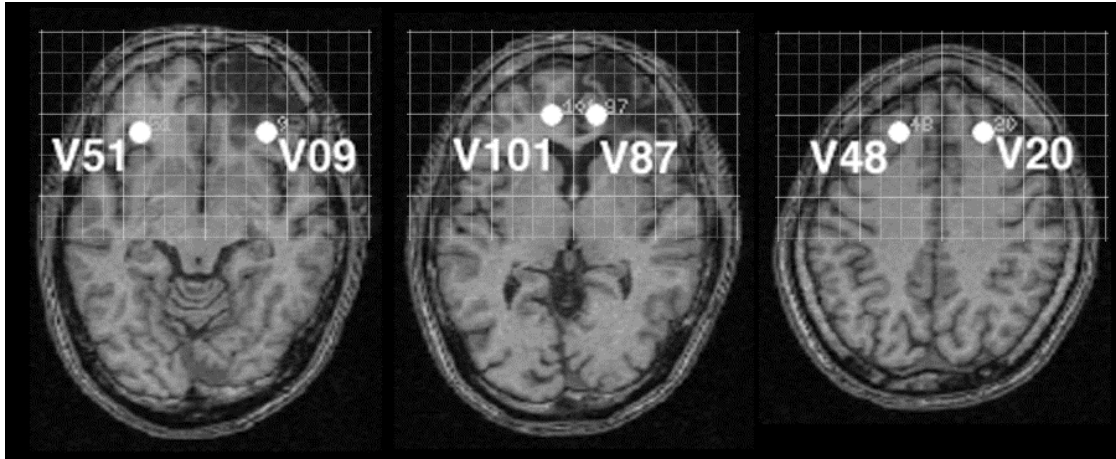
Figure 2a: *MR image of Case No.9 showing contusional change in the right frontal lobe. Lattices of 0.3 cm width were virtually set on the 3 dimensional MR image space. The currentodensitogram from virtual channel on each lattice point was monitored. The location of virtual channels being demonstrated in Figure 2b were specified.*
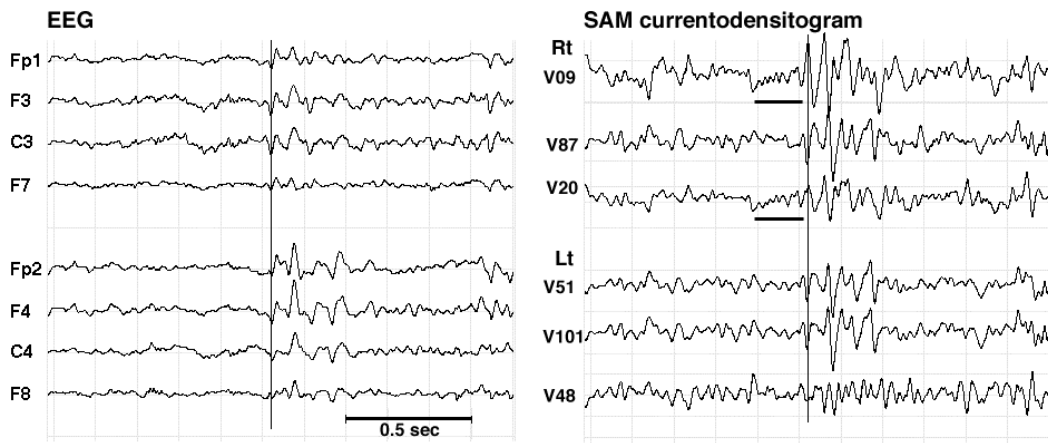

Figure 2b: *Simultaneous recording of EEG and SAM currentodensitogram of Case No.9. Selected channels are presented. SAM-VS currentodensitogram clearly disclosed large spike in the right frontal basal area (channel V09), while EEG demonstrated bilateral positive spikes, with which no localization could be determined (vertical line). Note the electrical still state identified on channels V09 and V20 prior to the spikes (underlines).*

The dominant hemisphere determined with reading task and SAM statistical method corresponded with the result of amytal test in all but one case because of incomplete reading task.

4 Discussion

Selection of patients for intracranial electrode implantation is based on the assumption that a given seizure disorder is focal. Nonlocalized seizures are, however, fond in about 20% of patient evaluated by intracranial recordings[5]. This is especially true in frontal lobe epilepsy, which is frequently medically intractable even with large resections, has worse surgical results than temporal lobe epilepsy, and is less understood. Possible causes of the problem with localization for epilepsy surgery are: large size of seizure focus [6], overlap of seizure focus and nonresectable essential areas, and inaccurate localization.

SAM virtual sensor method, introduced in this study , could discriminate ambiguous and heterogeneous electrophysiological process in the brain with superior spatial and time resolution as if intracranial electrodes covering whole brain were inserted. Advantages of this method would be quite suitable to delineate the epileptic focus hard to localize with conventional EEG/ECoG study, due to rapid propagation of electrical activity or to complex cortical electric fields that do not show any clear localizing features on visual analysis of EEG/ECoG[7]
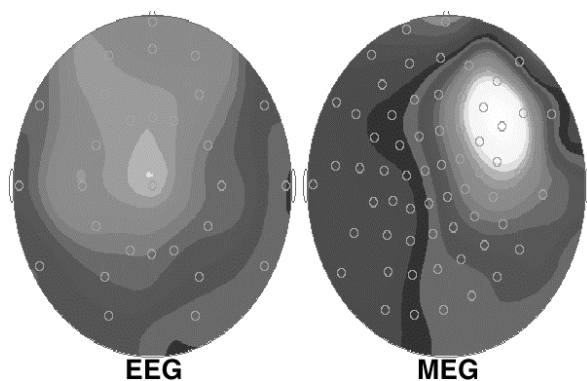
Figure 2c: *Topographies of EEG (left) and MEG (right) at the time of EEG spike as indicated in Figure 2b. The EEG topography indicated maximum voltage at Cz, while MEG topography strongly suggested the current source in the right frontal lobe.*
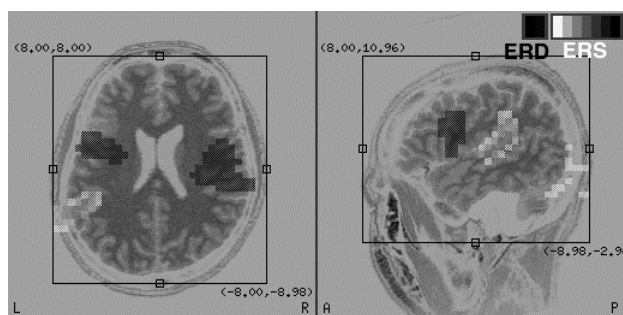

Figure 3: *Event related synchronization (brighter area) and desynchronization (darker area) of high frequency band (50-200Hz) developed during reading task in Case No.3. The SAM statistical image successfully demonstrated event related synchronization in Wernicke's area and desynchronization in Broca's area. This agreed with the result of Amytal test that left hemisphere was dominant.*

The localization of functional eloquent cortex is another important issue to determine the surgical detail. The SAM statistical method delineate the areas of functional cortex based on alteration of brain rhythm evoked by systemic neural activities. In the present study, we applied this method to demonstrate the language related cortices. The results obtained were reasonable. This analysis would be useful for the presurgical investigation especially in patients with medically intractable epilepsy because of non-invasiveness of the method and the simplicity of the task required [8].

5   Conclusion

Our results indicated that both of the SAM virtual sensor method and SAM statistical method would be effective in localizing normal and abnormal cerebral activities. These simple and noninvasive methods might become alternatives for invasive intracranial electrodes or amytal test. Further study is indicated to confirm their usefulness.

References

1. Widow, B., and Stearns, S.D. 1985. Beamformers with Superresolution: Adaptive Signal Processing. Prentice Hall, Upper Saddle River

2. Robinson. S.E., 1998. Method for functional imaging from magnetoencephalographic data by estimation of sour ce signal-to-noise ratio. US Patent Application.

3. Ninomiya H., Yoshimine T., Nii Y., et al. MEG study of temporal epilepsy -dipole analysis and synthetic aperture magnetometry (SAM)-, in *Recent Advances in Biomagnetism,* Yoshimoto T., Kotani M., Kuriki S., Karibe H., and Nakasato N., Eds. Sendai: Tohoku University Press, 1999, pp786-789.

4. Ishii R, Shinosaki K, Ukai S, et al. Medial prefrontal cortex generates frontal midline theta rhythm: *Neuroreport,* 10(4): 675-9,1999

5. Spencer, SS. Depth electroencephalography in selection of refractory epilepsy for surgery. Ann Neurol 1981, 9: 207-214

6. Rasmussen, T. Characteristics of a pure culture of frontal lobe epilepsy. Eplepsia 1983, 24:482-493

7. Sutherling, WW, Candall, PH, Engel, J, Darcey, TM, Cahan, LD, Barth, DS. The magnetic field of complex partial seizures agrees with intracranial localizations. Ann Neurol 1987, 21:548-558

8. Kato A, Yoshimine T, Taniguchi M, Robinson SE, Hirata M, Ninomiya H, Kihara T, Cheyne D, Hirabuki N, Nakamura H, Hayakawa T. Event-related desynchronization analyzed with SAM-SPM for functional brain mapping.. in *Recent Advances in Biomagnetism,* Yoshimoto T., Kotani M., Kuriki S., Karibe H., and Nakasato N., Eds. Sendai: Tohoku University Press, 1999, pp244-247.